

Performance Evaluation of Experimental Digital Optical Fiber Communication Link

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ABSTRACT: This paper deals with the Basic communication model and the types of fibers for the optical fiber communication system. Some basic concepts have been clarified that will determine the efficiency of the system. In order to evaluate the performance of the digital fiber optic communication system, a number of parameters have been studied by employing two wavelengths (1310, 1550) nm: the resulting attenuation from increase the length of fiber for single mode (SM) and multimode (MM) fibers, the bending losses, splices losses and the analysis of Q-factor and bit error rate (BER). Finally, a comparison has been made between three types of transmission channels: copper wires, radio frequency (RF) and optical fibers. Optical fiber was the faster channel to transfer the information.

KEYWORDS: Digital optical fiber link, Micro and macro bending, Splices in optical fiber, BER and Q-factor.

I. INTRODUCTION

The motivation for developing optical fiber communication systems started with the invention of the laser in the early 1960s, the use of and demand for optical fiber have grown tremendously. The uses of optical fiber today are quite numerous. With the explosion of information traffic due to the Internet, electronic commerce, computer networks, multimedia, voice, data, and video, the need for a transmission medium with the bandwidth capabilities for handling such vast amounts of information is paramount. Fiber optics, with its comparatively infinite bandwidth, has proven to be the solution.[1]. A fiber-optic data link consists of three parts: transmitter, optical fiber, and receiver. In addition, it includes any splices or connectors used to join individual optical fiber sections to each other and to the transmitter and receiver. Figure (1) is an illustration of a fiber-optic data-link connection. The transmitter, optical fiber, and receiver perform the basic functions of the fiber-optic data link. Each part of the data link is responsible for the successful transfer of the data signal.

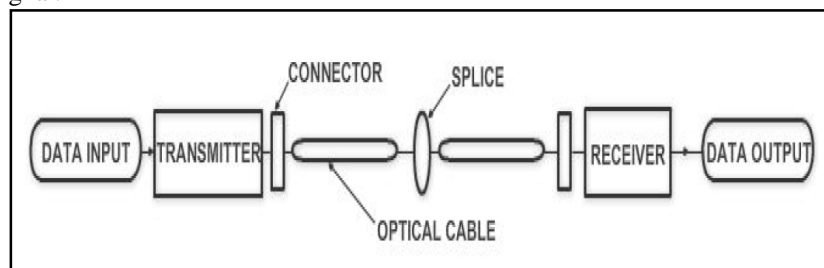


Figure (1): A schematic diagram of a point-to-point fiber-optic data link.

Point-to-point fiber optic links are the basic building block of all fiber optic systems. All fiber-optic systems are simply sets of point-to-point fiber optic links. Different system topologies arise from the different ways that point-to-point fiber optic links can be connected between equipment.

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II. FIBER OPTIC COMMUNICATION PERFORMANCE

Fiber losses represent limiting factor because they reduce the signal power reaching the receiver. As optical receivers need a certain minimum amount of power for recovering the signal accurately, the transmission distance is inherently limited by fiber losses. However, low-loss fibers are still required since spacing among amplifiers is set by fiber losses [2].

III. OPTICAL FIBER ATTENUATION

Attenuation represent the one most important characteristics of an optical fiber that determine the information-carrying capacity of a fiber optic communication system [3]. The fiber loss is referred to as signal attenuation or simply attenuation, which is an important property of an optical fiber because, together with signal distortion mechanisms, it determines the maximum transmission distance possible between a transmitter and a receiver (or an amplifier) before the signal power needs to be boosted to an appropriate level above the signal noise for high-fidelity reception. The degree of the attenuation depends on the wavelength of the light and on the fiber material [4]. Loss in a system can be expressed as the following [1]:

$$\text{Loss(dB)} = -10\text{Log}\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) \quad (1)$$

Where P_{in} is the input power to the fiber and P_{out} is the power available at the output of the fiber. Oftentimes, loss in optical fiber is also expressed in terms of decibels per kilometer (dB/km) [2]:

$$\alpha \text{ (dB/km)} = -\frac{10}{L}\text{Log}\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) \quad (2)$$

Where α is the attenuation coefficient.

The optical fiber can either be a single mode fiber (SM) or a multimode fiber (MM). A multimode fiber is used for short distance purposes; these fibers have high capacity and reliability. The main difference between a single mode fiber and a multimode fiber is that, the multimode fiber has a larger core diameter and also the value of its numerical aperture is large. Hence, the light gathering capacity of the fiber is high. In a multimode fiber the bandwidth distance product is much lower than that of a single mode fiber as the former supports more than one propagation mode. As well as, the attenuation coefficient (α) for single mode (SM) fiber is lower than multimode fiber (MM) [6].

IV. BENDING LOSS IN OPTICAL FIBER

Scattering and absorption loss due to the intrinsic characteristics of the optical fiber. As soon as the optical fiber is made, we can face these losses. In addition to these losses when any optical fiber is established inside the system, some losses take place due to environment and improper handling of the optical fiber [7]. Bend loss is a phenomenon which occurs when the optical fiber is bent above the critical bend radius. The bend radius varies for different optical fiber. Reasons for these bend loss are poor cable design, microscopic fiber deformation and tight bends. The bend loss can be of two types. They are: macro-bending loss and micro-bending loss, as illustrated in Figure (2). Macro bend loss occurs when the critical angle is exceeded at high order mode and the light is refracted out of the core into the cladding region. The macro bend loss can be seen with the naked eye and these bends can be rectified up to a certain extent. Micro bend loss is just opposite to the macro bend. Micro bend loss occurs when the pressure is applied on the surface of the fiber and due to the distortion of core cladding interface. The micro bend loss is too small to be seen with the naked eye [8].

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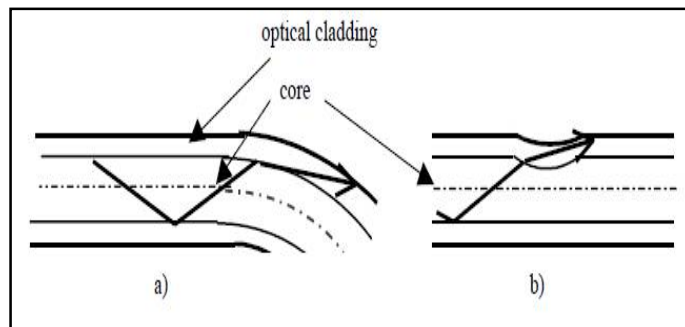


Figure (2): Losses by a- macro-bending, b- micro-bending

The single most important factor that determines the susceptibility of a fiber to bending that induces loss is the Mode Field Diameter (MFD). MFD represents the area in which the light goes through and includes the core and a part of the cladding. A smaller mode field diameter indicates that light is more tightly confined to the fiber center and, therefore, is less prone to leakage when the fiber is looped. Figure (3) shows the relationship of light power, MFD where diameter of core and the wavelengths are the important parameters in determining the sensitivity of bend loss [9].

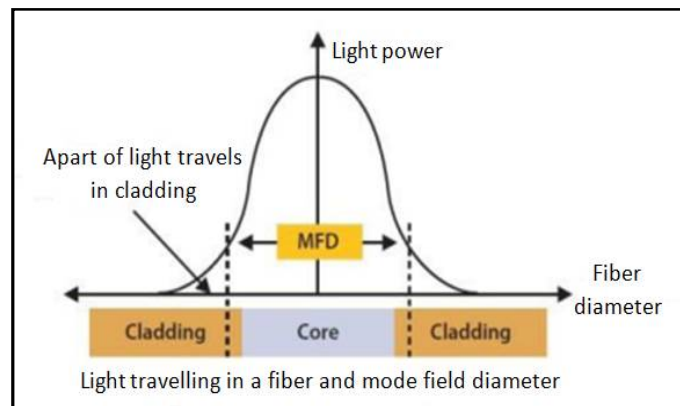


Figure (3): The relationship between light and MFD

V. SPLICES LOSS

A fiber splice is a permanent or temporary low-loss bond between two fibers. Such a bond can be made by using either fusion splicing or mechanical splicing. Most splices are permanent and typically are used to create long optical links or in situations where frequent connection and disconnection is not needed. The physical differences in fibers that lead to splice losses are the same as those discussed above for connectors and result in what is called intrinsic loss. These fiber-related differences include variations in core diameter, core-area ellipticity, numerical aperture, and core-cladding concentricity of each fiber. Extrinsic losses depend on how well the fibers are prepared and the care taken to make the splice. Generally speaking, splices offer a lower return loss, as shown in Figure (4), lower attenuation, and greater physical strength than connectors. Also, splices are usually less expensive per splice (or per joint) than connectors, require less labor, constitute a smaller joint for inclusion into splice closures, offer a better hermetic seal, and allow either individual or mass splicing.

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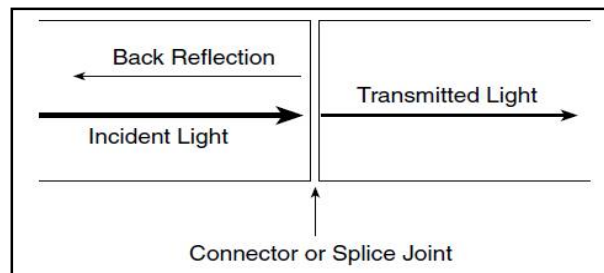


Figure (4): Optical return loss

VI. BIT ERROR RATE AND Q-FACTOR

In any an optical transmission system, the main purpose is to transfer data from one place to another with the least probability of inaccuracy. One of the main parameters describing the quality of the data link is a bit error rate BER (Bit Error Rate), with BER is possible to compare the quality of different systems for data transmission. But Q-factor characterizes the quality of a digital signal from an analog point. Q-factor and BER are the most important factors that limiting the transmission distance in optical communication systems. In order to transmit signals over long distances, it is necessary to have a low BER and high Q-factor within the fiber. The Q-factor can be used to give an approximate value for the BER, the relationship between Q-factor and the error rate can be expressed as follows[10,11]:

$$BER = \frac{1}{2} \operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{Q\sqrt{2\pi}} \exp\left(-\frac{Q^2}{2}\right) \quad (3)$$

Where erfc is the complementary error function. The Q-factor can be expressed in terms of the electrical signal-to-noise ratio (SNR) by the formula:

$$Q = \frac{SNR\sqrt{2TB_{opt}}}{1+\sqrt{1+2SNR}} \quad (4)$$

Where T is the bit period and B_{opt} is the bandwidth of the rectangular optical filter, and SNR is a measure used in science and engineering to quantify how much a signal has been corrupted by noise. It is defined as the ratio of signal power to the noise power corrupting the signal, as the following equation:

$$SNR = (I_1 - I_0) / I_0 \quad (5)$$

Here I_0 and I_1 are the means of the low-pass filtered electrical current at the sampling time for the spaces and marks [12].

VII. RUSTLES AND DISCUSSIONS

The channel is basically a medium which electrically connects the transmitter to the receiver. It may be a pair of wires, a coaxial cable, free space, optical fiber or even a laser beam. The properties of the channel can strongly influence the performance of a communication system. In this research, optical fiber is responsible for data transfer. During the process of transmission and reception, the signal gets distorted due to (i) distortion in the system and (ii) noise introduced in the system. The noise introduced is an unwanted energy, usually of a random character and may be caused by various sources.

The increase in transmission distance caused an increase optical power loss passer through optical fiber in communication system. When employment the wavelength (850nm) to transfer the data from one point to another. The losses was larger than the use of wavelengths 1310nm and 1550nm for the two types of fiber SM and MM, as illustrated in Figure (5). As well as the loss in SM fiber was smaller than the use of MM fiber.

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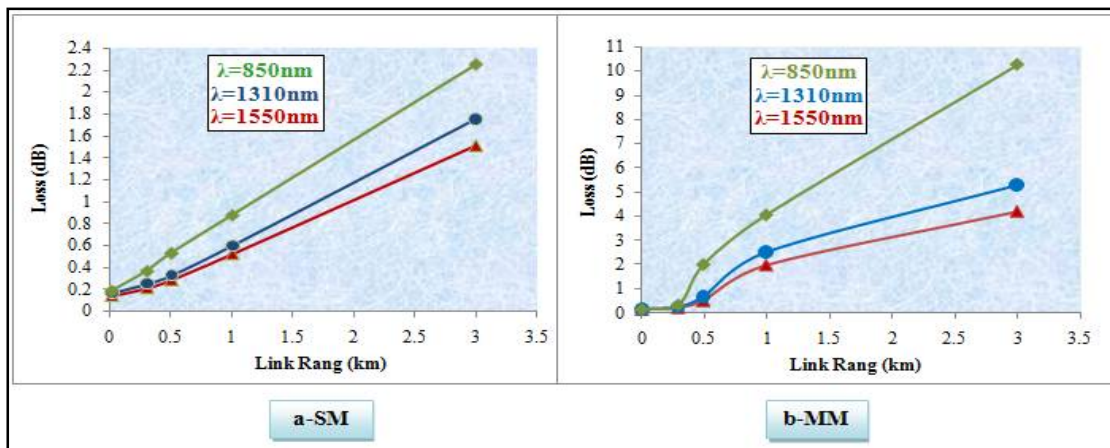


Figure (5): The losses for three wavelengths versus different link ranges for (a) SM and (b) MM

The following table illustrate that the use of the wavelength (1550) achieved better results for with SM and MM fibers. As well as the employment of SM fiber to transfer the information for long distances is better than the use of MM fiber for the three wavelengths.

There are two important criteria for evaluating link performance BER, Q-factor. The figures (6) and (7) explain the change in BER and Q-factor values as link ranges change. The following figures showed that the use of the wavelength (1550) achieved better results for with SM and MM fibers. As well as the employment of SM fiber to transfer the information for long distances is better than the use of MM fiber for the three wavelengths.

When we place the fiber inside the system, due to the improper placement of optical fiber, the fiber may deform in the micro scale region. This phenomenon called micro bending loss. Another type of loss takes place inside the optical fiber known the phenomenon of macro-bending loss. Bending losses change with wavelength for the two types of bending, it was observed that with increasing wavelength the bending losses increased. As shown in the Figure (8).

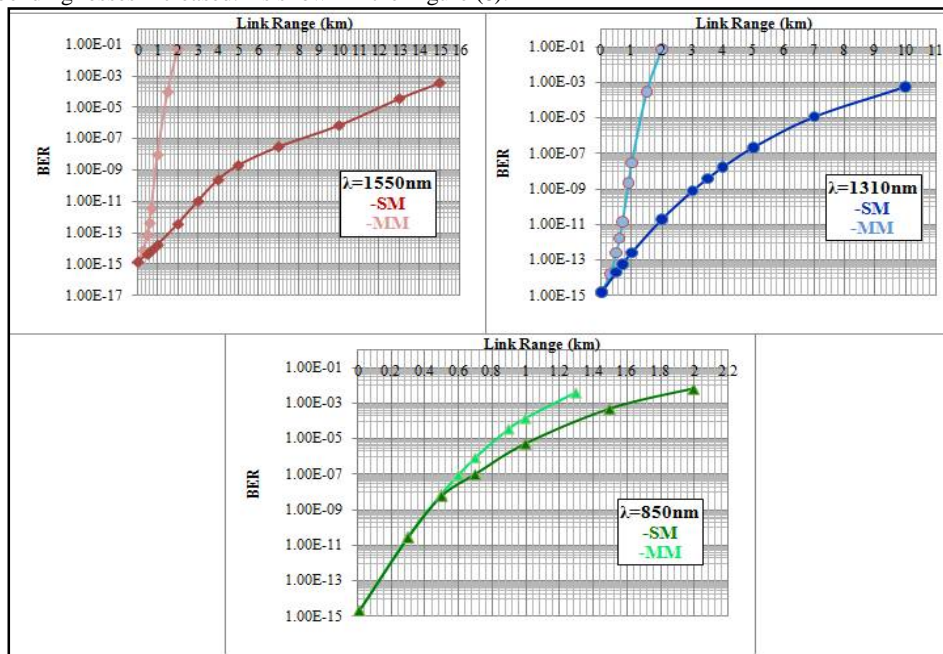


Figure (6): The increase of BER with increasing of link ranges in SM and MM fibers by using three wavelengths

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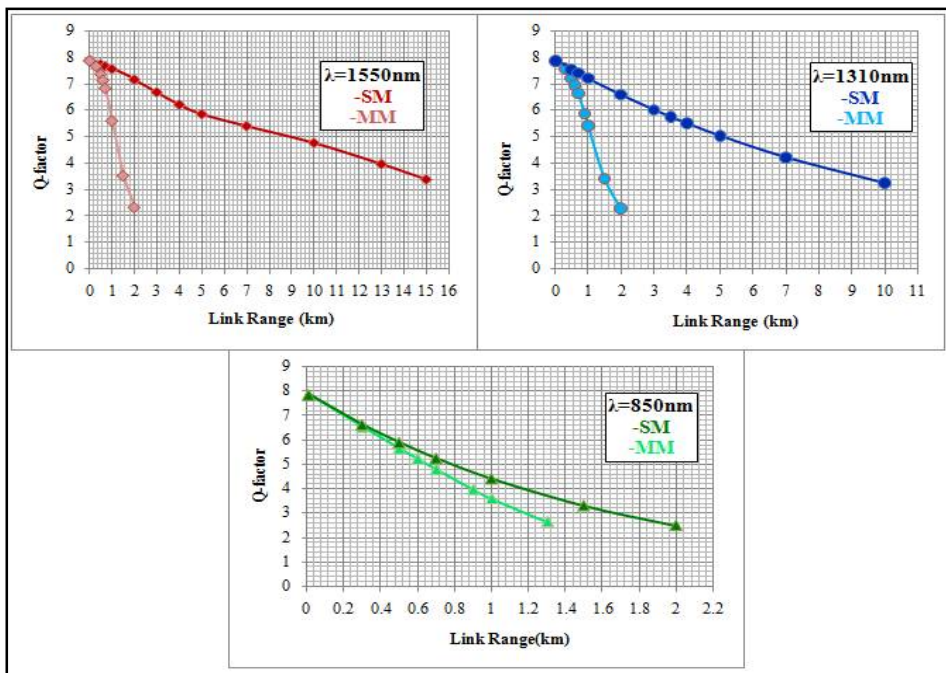


Figure (7): Q-factor versus link ranges in SM and MM fibers by using three wavelengths

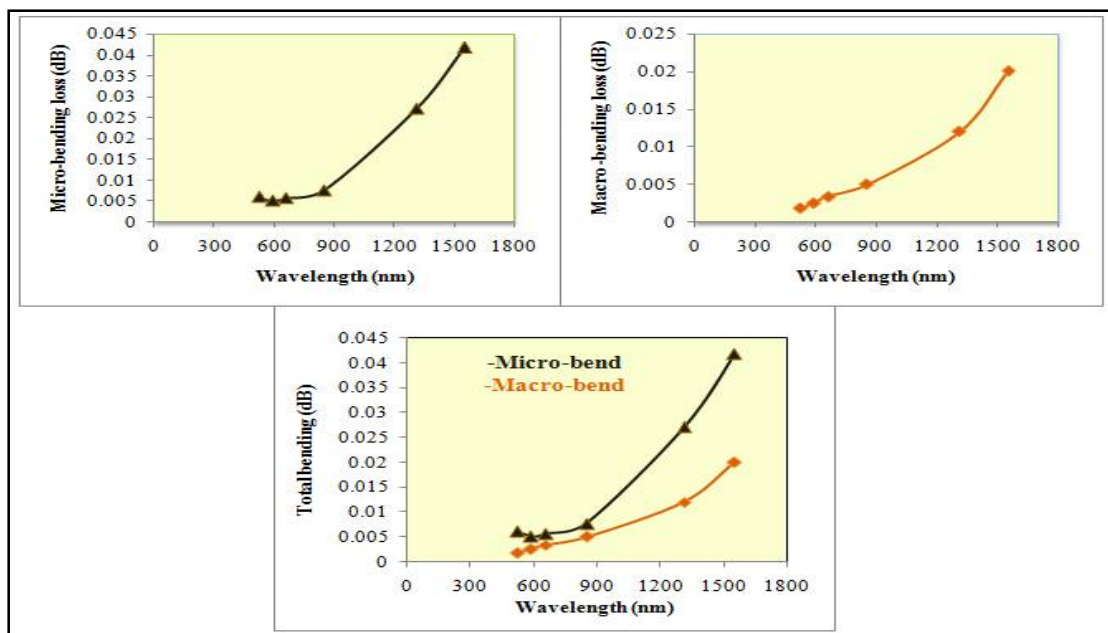


Figure (8): The bending loss vs. wavelengths for micro and macro bending

Then, the wavelengths (1310nm) and (1550nm) employed to study the effect of increase the number of defects on the two types of bending for (SM) and (MM) fibers. As shown in Figure (9).

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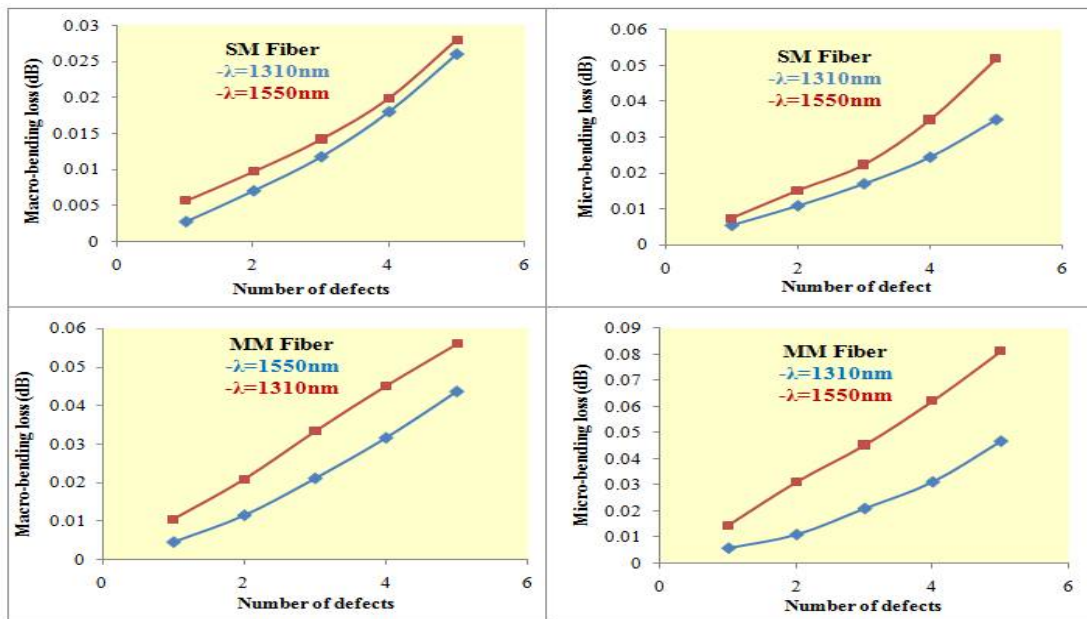


Figure (9): Change bending loss with increasing number of defects for two wavelengths (1310nm) and (1550nm) in SM and MM fibers

Table (1) and (3) show SNR, Q-factor and BER results for two wavelengths (1310, 1550) nm at using SM and MM fibers.

Table (1): SNR, Q-factor and BER due to micro-bending over SM and MM fibers at using the wavelengths (1310, 1550)nm

SM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of defects	SNR	Q - factor	BER E-16	No. of defects	SNR	Q -factor	BER E-16
1	63.56	7.9731	7.89	1	65.507	8.094	2.94
2	63.545	7.9715	7.96	2	65.479	8.092	2.98
3	63.525	7.9703	8.04	3	65.471	8.0915	2.99
4	63.5	7.9687	8.18	4	65.463	8.09	3
5	63.41	7.963	8.52	5	65.377	8.085	3.14
MM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of defects	SNR	Q - factor	BER E-17	No. of defects	SNR	Q -factor	BER E-17
1	69.988	8.366	3.02	1	69.329	8.3263	4.23
2	69.974	8.365	3.046	2	69.219	8.32	4.47
3	69.958	8.364	3.073	3	69.209	8.3189	4.49
4	69.936	8.3627	3.11	4	69.193	8.3181	4.53
5	69.908	8.361	3.15	5	69.171	8.317	4.58

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Table (2): SNR, Q-factor and BER due to macro-bending over SM and MM fibers at using the wavelengths (1310, 1550)nm

SM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of defects	SNR	Q -factor	BER E-16	No. of defects	SNR	Q - factor	BER E-16
1	63.701	7.9994	7.35	1	65.62	8.101	2.77
2	63.681	7.985	7.43	2	65.615	8.1	2.78
3	63.671	7.98	7.46	3	65.601	8.09937	2.803
4	63.651	7.9783	7.54	4	65.591	8.0985	2.82
5	63.621	7.9762	7.66	5	65.577	8.0976	2.84
MM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of defects	SNR	Q -factor	BER E-17	No. of defects	SNR	Q - factor	BER E-17
1	70.819	8.4156	1.99	1	69.988	8.366	3.02
2	70.809	8.4143	2	2	69.965	8.3645	3.06
3	70.785	8.414	2.02	3	69.937	8.3628	3.11
4	70.775	8.413	2.03	4	69.898	8.3605	3.17
5	70.752	8.4114	2.05	5	69.889	8.36	3.18

Low-loss fiber splicing results from proper fiber end preparation and alignment. In order to know the impact of the splices between the fiber optic and losses caused by them, a study was conducted by employing two wavelengths (1310nm) and (1550nm) in single mode and multimode fibers. As illustrated in the Figure (10).

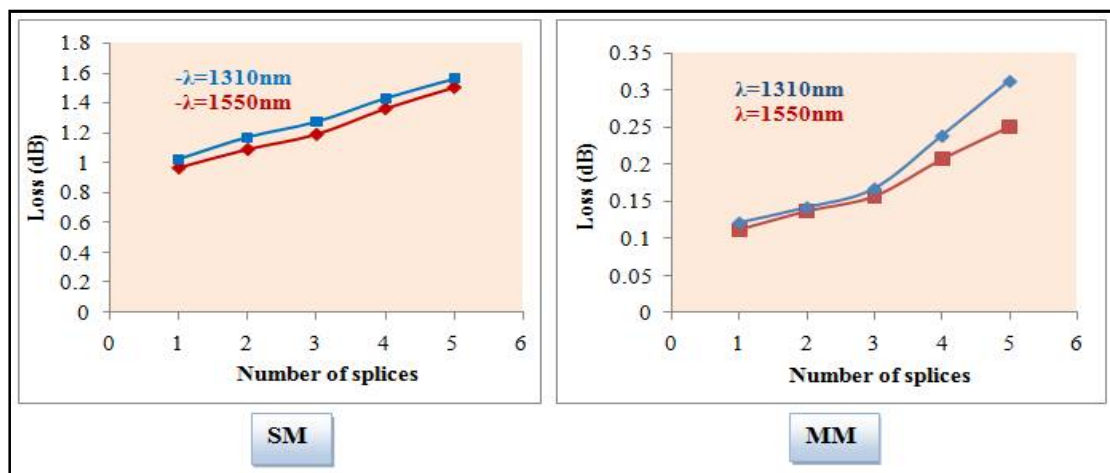


Figure (10): Loss fiber splicing versus number of splices

Table (3) shows that the increase in the number of splices between fiber optic causes an increase in BER and decreases in both SNR and Q-factor values in SM and MM fibers.

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Table (3): SNR, Q-factor and BER due to the splicing in SM and MM fibers at using the wavelengths (1310, 1550) nm.

SM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of Splices	SNR	Q - factor	BER E-16	No. of defects	SNR	Q - factor	BER E-16
1	63.5	7.9678	8.179	1	64.7835	8.049	4.244
2	63.32	7.9643	8.432	2	64.6535	8.041	4.533
3	63.3	7.959	8.81	3	64.63	8.0394	4.589
4	63.1	7.95	9.5	4	64.51	8.032	4.877
5	63.0414	7.94	10.3	5	64.431	8.027	5.07
MM							
$\lambda=1310\text{nm}$				$\lambda=1550\text{nm}$			
No. of Splices	SNR	Q - factor	BER E-17	No. of defects	SNR	Q - factor	BER E-17
1	71.2414	8.441	1.6	1	70.3	8.382	2.64
2	71.21	8.4385	1.63	2	70.22	8.3798	2.69
3	71.183	8.437	1.65	3	70.198	8.3785	2.72
4	71.1	8.435	1.72	4	70.146	8.3771	2.79
5	71.023	8.427	1.79	5	70.103	8.373	2.85

All previous studies have shown that fiber optic faster than copper wires (LAN) and RF to transfer the format from point to another point. This is consistent with the practical results that have been reached, as illustrated in Figure (11).

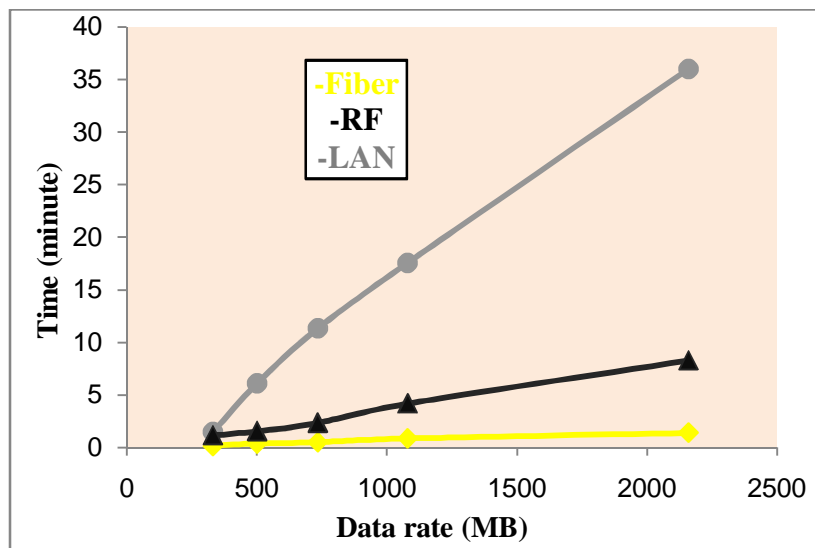


Figure (11): The velocity of data rate for Fiber, RF and LAN.

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